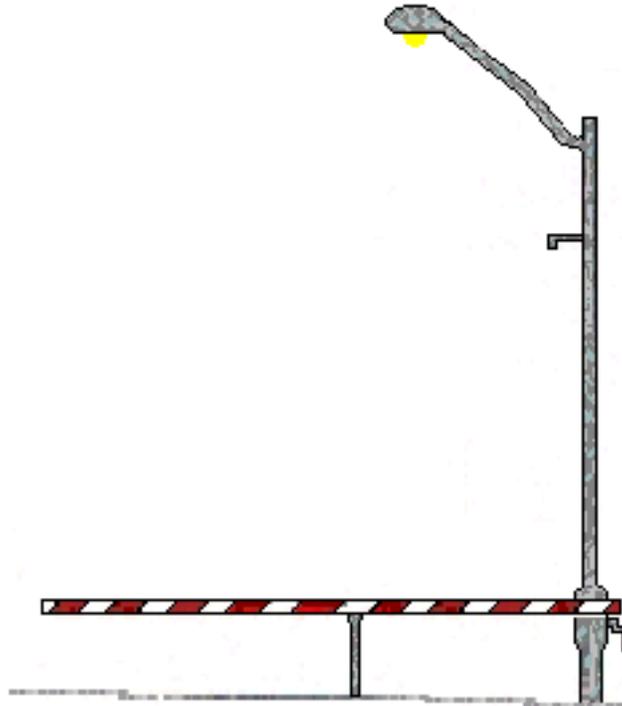


SD2000-11-F

South Dakota
Department of Transportation
Office of Research



Automated Road Closure Gate

Study SD2000-11
Final Report

Prepared by
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May 2000

DISCLAIMER

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Bill Cookson.....Office of Research
Brian Hines.....Office of Research
Dave Huft.....Office of Research

Dale Russell.....Rapid City Region
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<p>16. Abstract</p> <p>This report presents the procedures involved in the research, design, construction, and testing of an Automated Road Closure Gate. The current road closure gates used in South Dakota are often unsafe and difficult to operate. This report will assist the South Dakota Department of Transportation in determining whether a remotely controlled drive unit in combination with the new gate design (Project No. PH0902(00)55) is cost effective.</p> <p>Completion of the project was to involve executing fourteen tasks to fulfill three objectives. The objectives could not be fully met due to installation delay of the gate that was to be used on this project. The objectives were to design, build a functional prototype, and install a remotely activated road closure gate. The first was fully met, the second partially met, and the third was not met. Research was first performed pertaining to remotely activated road closure systems. The researchers then met with the Project's Technical Panel and South Dakota School of Mines and Technology (SDSM&T) Professors to discuss any issues or concerns they had with the project. A conceptual design was developed and approved by the Technical Panel and SDSM&T Professors. A preliminary design was developed and approved. The preliminary design was modified to accommodate a scaled model of the gate. The scaled model of the Automated Road Closure Gate was built and tested in the laboratory. An unsuccessful attempt was made to calculate the crash worthiness of the new system. The findings and recommendations were presented to the Research Review Board in a presentation on April 4, 2000. The findings included the following: Low quality parts used for the prototype and scale model proved to be unreliable. Complex Programmable Logic Devices may not have been the best processing units to use in the design. A linear actuator made by Jordan Controls was determined to be the best drive unit to raise and lower the gate. The recommendation for the road closure gate is to purchase a gate similar to the proposed design. Hy-Security is the recommended vendor for this purchase. Recommendations for future projects with student researchers are provided in the Implementation Recommendations section of this report.</p>			
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Chapter One

Executive Summary

This report presents the procedures, findings, and recommendations arising from the research, design, construction, and testing of a small-scale prototype Automated Road Closure Gate. Road closure gates currently used by the South Dakota Department of Transportation (SDDOT) are comprised of a gate that is hinged to a post. These gates are used to close roads to vehicular traffic during hazardous travel conditions brought on by inclement weather (i.e., snowstorms, ice storms, etc.). Deployment of these gates requires having SDDOT personnel manually swing the free end of the gate out across the roadway. Snow and ice buildups on the roadway and on and around the gate can make gate deployment difficult. Poor visibility and slippery conditions, which typically accompany the need for road closure, can make this deployment hazardous to SDDOT personnel. A change in the road closure gate design, along with the ability to remotely deploy the gate, may reduce the labor and hazard associated with using road closure gates. The current road closure gates used in South Dakota are often unsafe and difficult to operate. This report will assist the South Dakota Department of Transportation in determining whether a drive unit in combination with the new gate design (Project No. PH0902(00)55) is a cost-effective investment.

Research Objectives

The technical panel overseeing Research Project SD 2000-11 “Automated Road Closure Gate”, defined the following objectives for the study:

- 1. To design a remotely activated road closure system.*
- 2. To build a functional prototype of the road closure system.*
- 3. To install and demonstrate the functionality of the system to the Department of Transportation.*

The results of SDDOT Research Project SD 2000-11 presented herein address objective number 1. Objectives 2 and 3 were partially met by instead building and testing a small-scale road closure gate system. This change was caused by an unexpected delay in installation of the road closure gate, which was to be used on the research project.

Research Approach

The initial intent of the project was to carryout the fourteen specific tasks listed below. Delay in the installation of the prototype road closure gate did not adversely effect completion of tasks 1 through 7, 10, 13, and 14. Tasks 8, 9, 11, and 12 were modified because of a delay in prototype road closure gate installation:

- 1. Conduct a review of literature pertaining to remotely activated road closure systems.*
- 2. Meet with the technical panel to discuss any issues or concerns they may have with the project.*
- 3. Meet with South Dakota School of Mines and Technology professors to discuss critical issues related to the project.*
- 4. Develop a conceptual design of the system.*
- 5. Meet with and receive guidance from the Technical Panel and South Dakota School of Mines and Technology professors regarding the conceptual design of the system.*
- 6. Develop a preliminary design of the system.*
- 7. Present the preliminary system design to the Technical Panel and South Dakota School of Mines and Technology professors and receive guidance.*
- 8. Build and perform lab tests on a prototype of the system.*
- 9. Perform field tests on the system. Technical Panel shall be present during these field tests.*
- 10. Review crash test results of Wyoming Road Closure Gate (Transportation Research Board Record No. 1528) and calculate what effect mounting prototype equipment (sensors, actuator, etc.) will have on crash worthiness of gate.*
- 11. Meet with the technical panel and present the results of the field tests and receive direction regarding any needed system changes or repairs.*
- 12. Institute and test any necessary changes/repairs to system.*
- 13. Prepare a final report summarizing research methodology, findings, conclusions, and recommendations. This report shall also include system design details, to include schematics and wiring diagrams.*
- 14. Make an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project.*

Findings and Conclusions

This project studied the option of replacing the current swing-type gates with automated drop-arm gates. The new gate system design may allow safer and easier operation.

Finding 1:

The use of low cost electrical components for the model prototype proved to be inadequate. In an attempt to limit costs, low quality/cost components were used for all electrical circuitry. These components proved to be unreliable, unstable and easily breakable.

Finding 2:

The use of another device to control the transmitter and receiver circuits may have been beneficial. The researchers decided to use Complex Programmable Logic Devices (CPLDs) as the main processing units in the transmitter and receiver circuits. Although CPLDs do have many advantages over other processing units, there was one major disadvantage. The researchers did not have a dependable method of programming the CPLDs. The prototyping board used to program the CPLDs was an older version meant to be used with a previous software version. The older software could not be obtained, thus a newer version of the software was used. Using the new software with the older board could be a reason the CPLDs were not being programmed reliably. Another potential reason for the unsuccessful CPLD programming is simply that the prototyping board was old and outdated. Possibly Programmable Integrated Circuits (PICs) or microcontrollers could have been used in the circuits rather than the CPLDs.

Finding 3:

The designs considered for operating the gate varied from electric motors, to electric motors with gearboxes, to hydraulics, to linear actuators.

The problem with an electric motor/gearbox is that the torque that would be on the gearbox is comparable to the torque experienced by a 200 HP car. In order to get a motor/gearbox combination that can handle this torque the weight and price of the unit would be tremendous. This unit also would not function very well in the extremely cold temperatures. Also, through investigation it was determined that there may be some safety issues with disengaging the automated system so it can be operated manually.

The problems that a hydraulic unit would endure are that they will not function well in the extremely cold conditions. Additionally, they have proven to be fairly high maintenance in other gate designs. Building an enclosure around the hydraulic system and installing a heater, triggered by a thermostat, would allow it to operate at low temperatures. However, enclosing this system would make the drive unit large and heavy, meaning the pole may have to be crash tested again and may not pass. Similar to the electric motor/gearbox, this system has safety issues with disengaging the automated system to operate it manually.

A linear actuator built by Jordan Controls has been investigated and determined that it would be ideal for this application. This linear actuator develops around 1,600 lbf. Due to a built in heater, it works in adverse temperatures (-40 to 150 °F). The actuator has a manual hand-wheel, which eliminates the need for the hand winch that is presently in the design PH 0902(00)55. Additionally, this unit is low maintenance and is permanently lubricated.

Implementation Recommendations

In conclusion of the study, a recommendation for the installation of a commercially made automated road closure gate is made. Additionally, several recommendations for future projects with students from the South Dakota School of Mines and Technology are made.

Recommendations for the Automated Road Closure Gate

Recommendation 1:

Purchase a commercially made Automated Gate (estimated cost \$6,000) with the following features:

1. Heater
2. Key-switch and Radio Control
3. 32 ft. Aluminum/Fiberglass Arm with Low Voltage Flashing Lights
4. Linear Actuator or Hydraulic Driven
5. Passed Government Crash Test Standards

The purchase of a commercially made and installed Automated Road Closure Gate was evaluated to be more economical than designing and building a gate.

Recommendations for Future Projects with SDSM&T Students

Recommendation 1:

Have separate and modified guidelines for student research projects. In addition to the SDDOT research guidelines, student researchers have additional guidelines given to them by their school. A compromise set of guidelines should be made that will accommodate SDDOT and SDSM&T requirements.

Recommendation 2:

Have a clear Project Statement for the students at the beginning of the project. As student researchers have only a few months for design and completion of a project, a clear and concise Project Statement is highly recommended.

Recommendation 3:

Meet with the SDSM&T Faculty before the project starts. A meeting between faculty and researchers will ensure both faculty and SDDOT are in agreement on the project goals and expectations of student researchers.

Chapter Two

Problem Statement

Road closure gates currently used by the South Dakota Department of Transportation (SDDOT) are comprised of a gate that is hinged to a post. Deployment of the gate requires SDDOT personnel to manually swing the free end of the gate out across the roadway. Snow and ice buildups on the roadway and on and around the gate can make gate operation difficult. Poor visibility and slippery conditions, which typically accompany the need for road closure, can make this deployment dangerous to SDDOT personnel. A change in the road closure gate design along with automation of the closure mechanism may reduce the labor and danger associated with deployment of road closure gates.

Background Summary

The current road closure gates used by the South Dakota Department of Transportation (SDDOT) are comprised of a gate that is hinged to a post. A prototype of a different gate design has been bid and will be constructed by February 2000. This new gate will be located at exit 55 in the westbound lane of I-90. The gate will be a drop down gate rather than a swinging gate. The gate will have a manual crank to lower and raise the gate. The gate will have warning lights located on the gate and on warning signs located one-half mile ahead of the gate. A detailed plan for the gate can be found in the plans for Project No. PH 0902(00)55.

The new road closure gate design is expected to increase the safety of opening and closing the gate. But, the problem of difficult gate operation due to snow and ice build up still remains. Also, the problem of not being able to reach the gate due to snowdrifts or other barriers remains. The proposed automated system for the gate would help eliminate both of these remaining problems. The system would include a motor device attached to the gate for raising and lowering the gate. This motor could be operated by either a switch located at the gate or by a short range remote control system.

This proposed system would not be implemented on all future drop gates in South Dakota, but simply used as an evaluation tool to determine if the increased safety and ease of use associated with the system would be worth the investment required to commercially purchase similar products.

Chapter Three

Objectives

The primary objective of this research project was to create a safe and reliable automated road closure system that is easy for SDDOT employees to operate in extreme weather conditions.

Objective 1:

To design a remotely activated road closure system.

This objective was met by designing a system with the following features:

- 1) A motor device to raise and lower the gate.
- 2) A switch at the gate that operates the motor device.
- 3) A remote system that will allow a user short range remote control of the gate and warning light operations.

After close analysis of various motor/actuator methods for gate operation, it was concluded that a linear actuator with manual override capabilities should be used. The linear actuator selected allows for both electric operation of the gate and manual operation using a hand crank.

A method for closing the gate and initiating warning lights or opening the gate and turning off the warning lights is via key switch located on the gate's electrical box. The purpose for the key switch method versus a push button is to ensure secure operation of the gate and warning lights.

Finally, a short-range (approx. 30 ft) remote control device enables the user to operate the gate and warning lights without direct contact with the gate. The user will input a four-digit sequence on a keypad that will be processed and transmitted to the receiver located in the gate's electrical box. The code is then further processed to determine what gate and warning lights operation command was issued. The code is representative of three entities: 1) the highway number representative of the gate to be controlled, 2) the lane direction of traffic (east/west) and 3) the command to either open the gate and activate warning lights or close the gate and deactivate warning lights.

Objective 2:

To build a functional prototype of the road closure system.

This objective was partially met. A scaled model of the road closure gate was built and a stepper motor (for simulation purposes only) was used in place of the linear actuator proposed for the actual gate. The remote control system was built and designed and the switch control was integrated into the electrical system at the gate. In order to maintain a small budget for the prototype model, low quality electrical components were used. Unfortunately, due to the components' poor quality, the electrical system was unreliable.

Objective 3:

To install and demonstrate the functionality of the system to the Department of Transportation.

This objective was to be met by installing the remote system and motor device into the road closure gate at the I-90 West Exit 55. This was unable to be completed as the gate installation was delayed.

Chapter Four

Task Description

The work plan and methodology for carrying out the research objectives is detailed below. The information obtained in the accomplishments of these tasks is discussed in greater detail in *Chapter Five*.

Task 1:

Conduct a review of literature pertaining to remotely activated road closure systems.

The researchers studied similar gate operation systems including those used for road closure gates in other states, railroad crossing gates, and security gates. The researchers also studied remote control devices including transmitter/receiver pairs and smart microphone systems using two-way radios.

Task 2:

Meet with the technical panel to discuss any issues or concerns they may have with the project.

The researchers met with the Technical Panel to review the agenda of the project and the intended work plan. The meeting was used to give the panel a chance to ask questions and to provide any suggestions on the topic. Additionally, this meeting gave the researchers a chance to ask questions of the Technical Panel in order to clarify the projects objectives.

Task 3:

Meet with South Dakota School of Mines and Technology professors to discuss critical issues related to the project.

On several occasions, the researchers met with and discussed various aspects of the project with four SDSM&T professors, Dr. Brian Hemmelman, Dr. James Cote, Dr. Dan Dolan, and Dr Neil Chamberlain. The professors contributed advice and guidance to the researches in all phases of the project. Dr. Brian Hemmelman gave the researchers guidance with the digital design portion of the project. Dr. James Cote gave the researchers guidance with the motor control portion of the project. Dr. Dan Dolan gave the researchers guidance with the drive unit selection process. Dr. Neil Chamberlain gave the researchers guidance with the wireless communication portion of the project.

Task 4:

Develop a conceptual design of the system.

The researchers developed a conceptual design of the system (Appendix A). This design contained no details of the design, but instead contained the basic functionality of the design.

Task 5:

Meet with and receive guidance from the Technical Panel and South Dakota School of Mines and Technology professors regarding the conceptual design of the system.

The researchers informally presented the conceptual design to the Technical Panel and SDSM&T professors. This gave the Technical Panel and SDSM&T professors an opportunity to make changes to the design. Neither the Technical Panel nor the SDSM&T professors had any suggested changes for the researchers.

Task 6:

Develop a preliminary design of the system.

A preliminary design of the system was designed based upon the conceptual design. The design is more detailed than the conceptual design (Appendix B). The following is an overview of the major elements in the preliminary design.

- A CPLD (Complex Programmable Logic Device) was chosen to be the programmable hardware logic device of the system. This was chosen because it has static memory, low cost and reliability. Additionally, the designers chose the CPLD as they are familiar with the language used to program the device. Very High Speed Integrated Circuit Hardware Description Language (VHDL) was used to program the CPLDs (Appendix C).
- The Summing of the Moments Principle was used to determine the force needed to operate the gate.). Using a dynamic moment equation, the maximum load limit was calculated to be 1150 lb (Appendix D). A decision matrix was used to determine that an actuator would be the best drive system. The variables used in the decision matrix are as follows: reliability, cost, maintenance, weight, operation in extreme weather, ease of manual override, and need for counter weight. Additionally, the actuator chosen has internal limit switches that can be adjusted and a manual override system that is easy and safe. (A manual override capability was a design requirement set forth by Dale Russell of the Regional Office of the SDDOT. Dale Russell was the primary engineer for the gate design.)
- A RF (Radio Frequency) signal was determined to be the best choice for the remote control operation of the gate and warning lights. This was chosen as the transmission mode because it is the only wireless mode with the needed range of operation.
- A Ming® TX-66 transmitter and RE-66 receiver pair were selected for the transmission and reception of the signal from the remote control device. The primary reasons for this selection are the following: low-cost, appropriate range, secure 12-bit data transmission, and low transmission bit-error rate.
- A crystal oscillator was selected to provide a clock signal used for the CPLD. The crystal-based oscillator has low variation of frequency due to temperature change.

Task 7:

Present the preliminary system design to the Technical Panel and South Dakota School of Mines and Technology professors and receive guidance.

The researchers informally presented their preliminary design to the Technical Panel and SDSM&T professors. During a discussion with a member of the Technical Panel, the researchers were informed that the new barrier arm style road closure gate would not be constructed before the completion of the research project. The researchers and the Technical Panel agreed that a model of the gate and the automated system would be constructed and tested. At this time the design was modified in order to accommodate a 1/12-scale model (Appendix E). This included changing the drive unit from a linear actuator to a stepper motor, and using less expensive, but poorer quality, electrical components.

Task 8:

Build and perform lab tests on a prototype of the system.

The system described in the preliminary design and modified for a scale model was constructed and tested within a lab environment. The remote system will first be tested independently of the motor device.

- The VHDL code for the CPLD was tested and verified using Xilinx® software licensed to SDSM&T.
- The encoder/transmitter and receiver/decoder devices were tested by entering numerous 4-bit data strings into the encoder/transmitter. By using a breadboard and four LEDs (Light Emitting Diodes) it was determined that the receiver/decoder output matched the input of the encoder/transmitter. This proved to work up to a distance of 30 ft using a 9volt battery as a power supply for the encoder/transmitter.
- The transmitter circuit (Appendix B.1) was tested first to determine if the CPLD was sending the correct data bits to the encoder/transmitter device. After determining that the CPLD was not sending the correct data bits to the encoder/transmitter device, the CPLD was reprogrammed allowing the researchers to determine if the CPLD was correctly determining the keys being pressed on the keypad. This proved to also be unsuccessful. The CPLD was reprogrammed several times with varying results each time. Because the code was simulated successfully, it was determined that the method the researches used to download the code into the CPLD was unreliable. This was believed to be a problem with prototyping board.
- The receiver circuit was also tested (Appendix B.2). The same problems arose in the receiver circuit that was prevalent in the transmitter circuit.
- The stepper motor was tested independently of the system by sending alternating pulses to four poles of the motor. The motor successfully rotated in both the clockwise and counter clockwise directions.
- The motor control chip was tested independently of the system by sending a square wave to the input of the device and checking the outputs using a digital oscilloscope. The motor control chips outputs were correct in both the clockwise and counter clockwise directions.
- Since both the transmitter and receiver circuits were not functional independent of the system, no tests were done on the entire system.

Task 9:

Perform field tests on the system. Technical Panel shall be present during these field tests.

Not performed due to the fact that only a model of the gate was built.

Task 10:

Review crash test results of Wyoming Road Closure Gate (Transportation Research Board Record No. 1528) and evaluate what effect mounting prototype equipment (sensors, actuator, etc.) will have on crash worthiness of gate.

The gate to be constructed, with exception of the drive unit, will be equivalent to the Wyoming gate that has passed crash tests. It will consist of a 29 ft. luminaire support pole with a 8-ft long mast arm and light. Furnished by Safetran®, the gate will be a 32 ft. fiberglass/aluminum arm with a cast adapter. Because all the components except the drive unit will be equivalent to Wyoming's design, the main focus of crash worthiness evaluations were given to the drive unit.

There is no absolute way without crash testing to verify that the gate is crashworthy. The only relevant difference to the Wyoming gate is the actuator and its orientation on the gate. In this design the heavy part of the actuator (motor) will be orientated towards the bottom of the pole. This will ensure that in the event a car hits this pole that the actuator will not break loose and fly through the window of the car. This was a recommendation made by Dr. Dan Dolan.

Task 11:

Meet with the technical panel and present the results of the field tests and receive direction regarding any needed system changes or repairs.

Not performed due to the fact that only a model of the gate was built.

Task 12:

Institute and test any necessary changes/repairs to system.

Dr. Brian Hemmelman gave the researchers a different prototyping board in order to try to accurately download the VHDL code into the CPLDs. This board proved to be more reliable, but due to time constraints, verification was not able to be completed.

Task 13:

Prepare a final report summarizing research methodology, findings, conclusions, and recommendations. This report shall also include system design details, to include schematics and wiring diagrams.

A summary of the automated road closure system design, implementation and testing was documented for the SDDOT. The report includes the reasons the researchers chose the particular design implemented and findings from lab tests. Recommendations are included as are the system details, schematics and diagrams.

Task 14:

Make an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project.

A presentation to the SDDOT was made on April 4, 2000.

Findings and Conclusions

This project studied the option of replacing the current swing-type gates with automated drop-arm gates. The new style gates would allow safe and easy operation of the road closure gate by SDDOT employees.

Finding 1:

The use of low cost electrical components for the model prototype proved to be inadequate. In effort to keep a small budget, low quality/cost components were used for all electrical circuitry. These components proved to be unreliable, unstable and break easily.

Finding 2:

The use of another device to control the transmitter and receiver circuits may have been beneficial. The researchers decided to use Complex Programmable Logic Devices (CPLDs) as the main processing units in the transmitter and receiver circuits. Although CPLDs do have many advantages over other processing units, there was one major disadvantage. The researchers did not have a dependable method of programming the CPLDs. The prototyping board used to program the CPLDs was an older version meant to be used with a previous software version. The older software could not be obtained, thus a newer version of the software was used. Using the new software with the older board could be a reason the CPLDs were not being programmed reliably. Another potential reason for the unsuccessful CPLD programming is simply that the prototyping board was old and outdated. Possibly Programmable Integrated Circuits (PICs) or microcontrollers could have been used in the circuits rather than the CPLDs.

Finding 3:

The designs looked into for operating the gate vary from electric motors, electric motors with gearboxes, hydraulics, and linear actuators.

The problem with an electric motor/gearbox is that the torque that would be on the gearbox is comparable to the torque experienced by a 200 HP car. In order to get a motor/gearbox combination that can handle this torque the weight and price of the unit would be tremendous. This unit also would not function very well in the extremely cold temperatures. Also, through investigation it was determined that there may be some safety issues with disengaging the automated system so it can be operated manually.

The problems that a hydraulic unit would endure are that they will not function well in the extremely cold conditions. Additionally, they have proven to be fairly high maintenance in other gate designs. Building an enclosure around the hydraulic system and installing a heater, triggered by a thermostat, would allow it to operate at low temperatures. However, enclosing this system would make the drive unit large and heavy, meaning the pole may have to be crash tested again and may not pass. Similar to the electric motor/gearbox, this system has safety issues with disengaging the automated system to operate it manually.

A linear actuator built by Jordan Controls has been investigated and determined that it would be ideal for this application. This linear actuator develops around 1,600 lbf. Due to a built in heater, it works in adverse temperatures (-40 to 150 °F). The actuator has a manual hand-wheel, which eliminates the need for the hand winch that is presently in the design PH 0902(00)55. Additionally, this unit is low maintenance and is permanently lubricated.

Implementation Recommendations

In conclusion of the study, a recommendation for the installation of a commercially made automated road closure gate is made. Additionally, several recommendations for future projects with students from the South Dakota School of Mines and Technology are made.

Recommendations for the Automated Road Closure Gate

Recommendation 1:

Purchase a commercially made Automated Gate (estimated cost \$6,000) with the following features:

6. Heater
7. Key-switch and Radio Control
8. 32 ft. Aluminum/Fiberglass Arm with Low Voltage Flashing Lights
9. Linear Actuator or Hydraulic Driven
10. Passed Government Crash Test Standards

The purchase of a commercially made and installed Automated Road Closure Gate was evaluated to be more economical than designing and building a gate.

Recommendations for Future Projects with SDSM&T Students

Recommendation 1:

Have separate and modified guidelines for student research projects. In addition to the SDDOT research guidelines, student researchers have additional guidelines given to them by their school. A compromise set of guidelines should be made that will accommodate SDDOT and SDSM&T requirements.

Recommendation 2:

Have a clear Project Statement for the students at the beginning of the project. As student researchers have only a few months for design and completion of a project, a clear and concise Project Statement is highly recommended.

Recommendation 3:

Meet with the SDSM&T Faculty before the project starts. A meeting between faculty and researchers will ensure both faculty and SDDOT are in agreement on the project goals and expectations of student researchers.

References

Recommended Purchase of Commercially Made Automated Road Closure Gate:

<http://www.hysecurity.com/>

Manufacturer of Transmitter/Receiver Pair:

<http://www.ming-micro.com/index.htm>

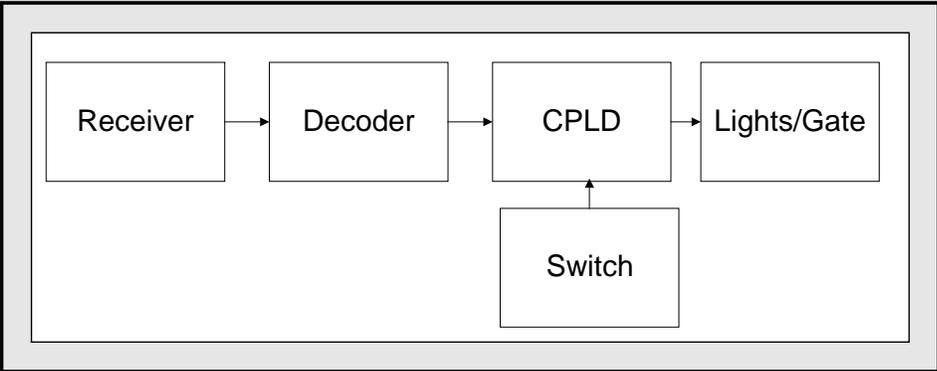
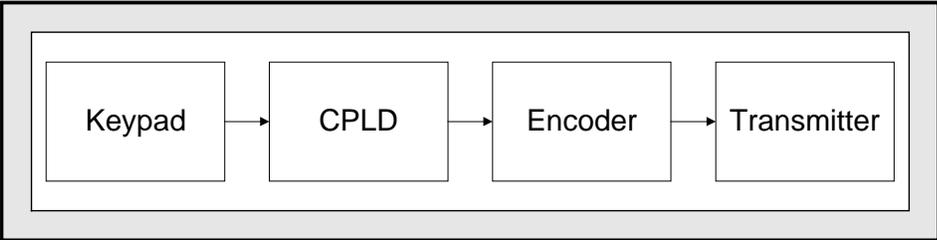
Manufacturer of Liner Actuator:

<http://www.jordancontrols.com/>

Manufacturer of aluminum/fiberglass gate arm:

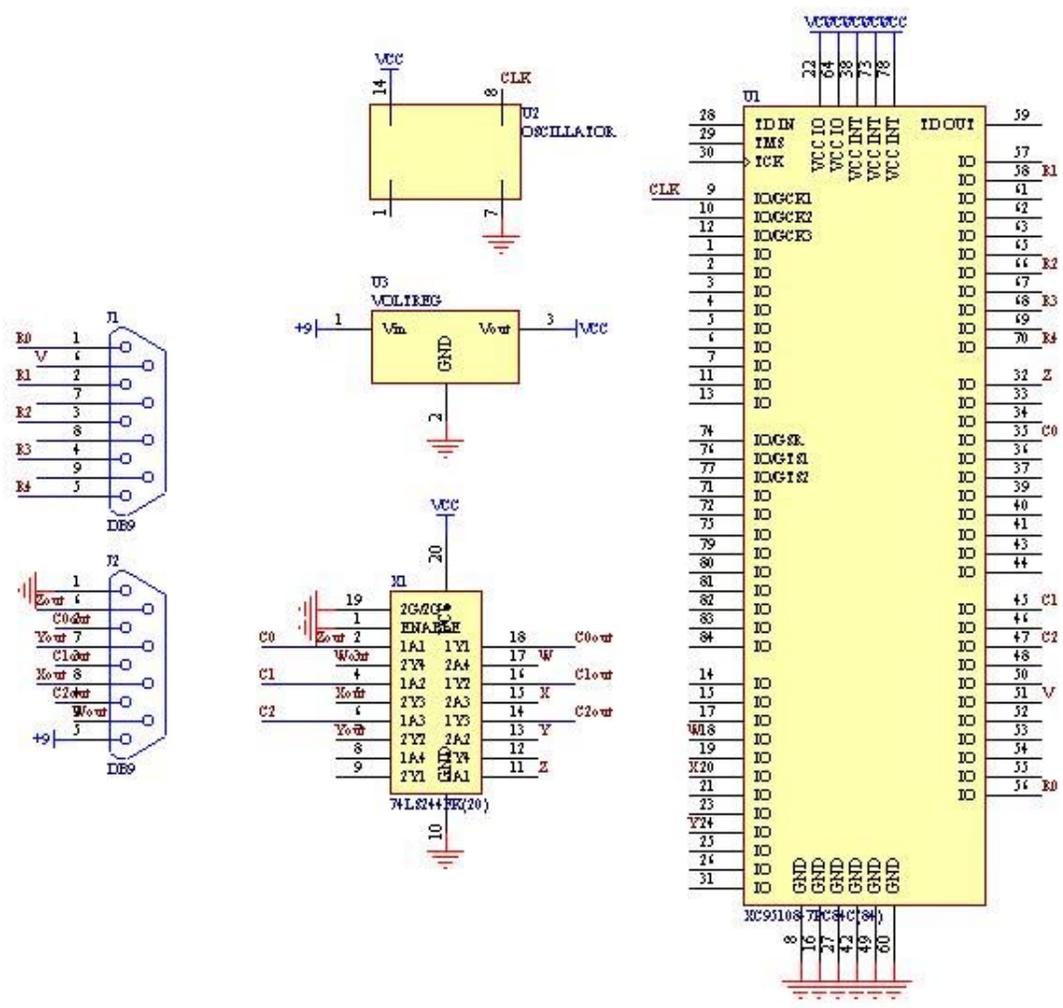
<http://www.safetran.com/>

Appendix A Conceptual Design



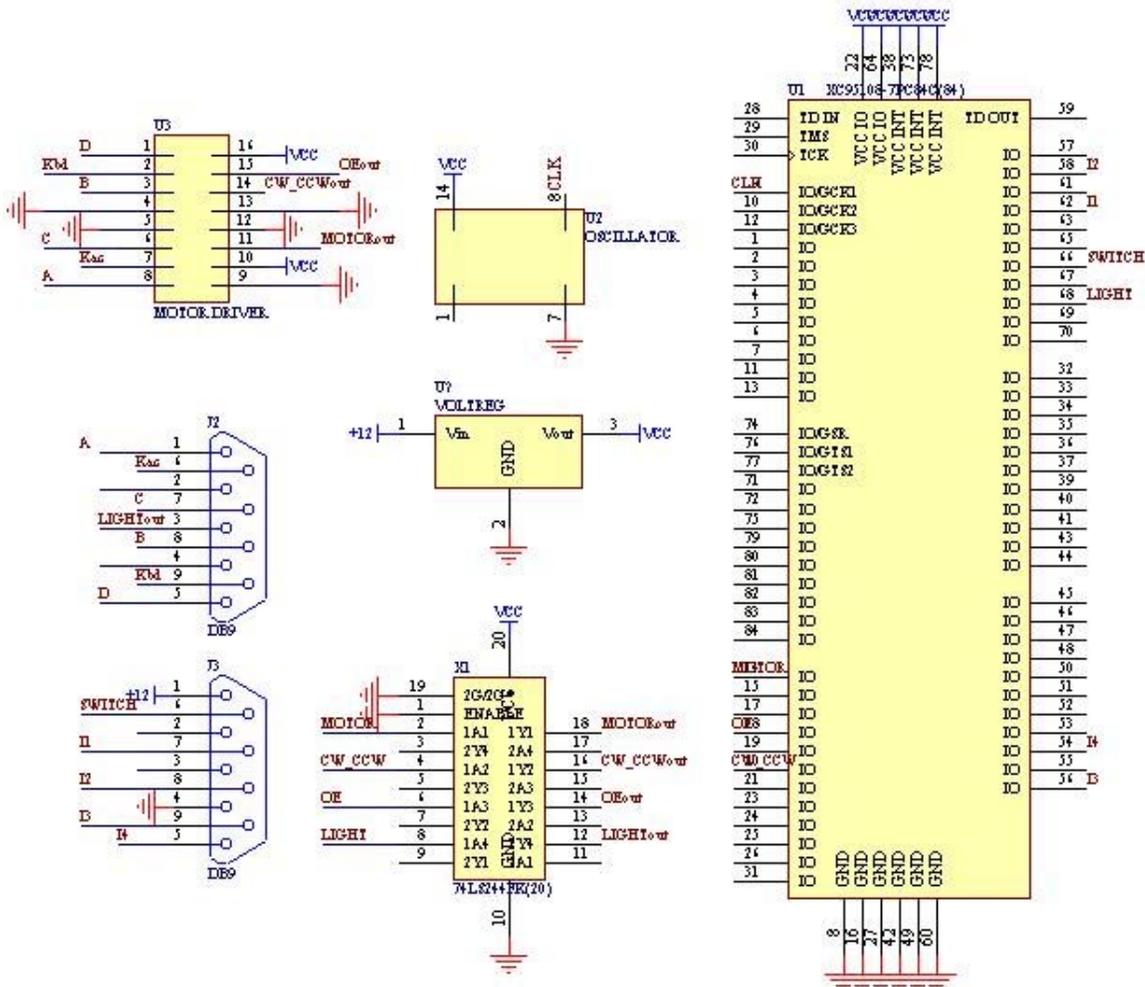
Appendix B Preliminary Design

Section 1 Transmitter Circuit



Appendix B Preliminary Design

Section 2 Receiver Circuit



Appendix C VHDL Code

Section 1 Transmitter Circuit

```
-- Title: Keypad Decoder VHDL
-- Author: Sara Russell Date: 11/2/1999 Last Revision: 4/16/2000
-- Description: This code determines the key being pressed by a keypad and then
--determines if the series of keys pressed is a valid code and sends that information to --a
encoder to be transmitted.
```

```
library ieee;
use ieee.std_logic_1164.all;
--use ieee.std_logic_unsigned.all;
use ieee.std_logic_arith.all;

entity transmitter is
  port (R0, R1, R2, R3, R4 : in std_logic;
        CLK, RST          : in std_logic;
        C0, C1, C2        : out std_logic;
        N0, N1, N2, N3    : out std_logic;
        W, X, Y, Z        : out std_logic);
end;

architecture transmitter_arch of transmitter is
  signal K : std_logic;

  -- 3-std_logic register that are cascaded on input rows
  signal R0_reg, R1_reg, R2_reg, R3_reg, R4_reg : std_logic_vector(3 downto 0);
  signal R0_rise, R1_rise, R2_rise, R3_rise, R4_rise : std_logic;

  -- simple counter starts at "0000", "0001", "0011", "0111", "1111"
  signal counter, n_counter : std_logic_vector(6 downto 0);

  signal col, n_col : std_logic_vector(1 downto 0);
  signal row, n_row : std_logic_vector(2 downto 0);
  signal num, n_num : std_logic_vector(3 downto 0);
  signal row_col : std_logic_vector(4 downto 0);
  signal number_updated : std_logic;
  signal W5, X5, Y5 : std_logic;
  signal n_W5, n_X5, n_Y5 : std_logic;

  type STATE_TYPE is (INIT, S0, S1, S2, DONE);
  type S_TYPE is (SS0, SS1, SS2, SS3, SS4, SS5, SS6);
  signal CURR_STATE, NX_STATE : STATE_TYPE;
  signal CURRENT_STATE, NEXT_STATE : S_TYPE;

begin

  -- Concurrent Statements
  N0 <= num(0);
  N1 <= num(1);
  N2 <= num(2);
  N3 <= num(3);

  -- Rising edge detect on the Rows
```

```

-- i.e. R0_rise will goto '1' for 1 clock cycle if there is rising edge on input R0
R0_rise <= R0_reg(1) and R0_reg(2) and (not R0_reg(3));
R1_rise <= R1_reg(1) and R1_reg(2) and (not R1_reg(3));
R2_rise <= R2_reg(1) and R2_reg(2) and (not R2_reg(3));
R3_rise <= R3_reg(1) and R3_reg(2) and (not R3_reg(3));
R4_rise <= R4_reg(1) and R4_reg(2) and (not R4_reg(3));

-- K is any active row after debounce
K <= R0_reg(1) or R1_reg(1) or R2_reg(1) or R3_reg(1) or R4_reg(1);

process (CLK, RST)
begin
  if RST = '1' then
    R0_reg      <= "0000";
    R1_reg      <= "0000";
    R2_reg      <= "0000";
    R3_reg      <= "0000";
    R4_reg      <= "0000";
    counter     <= "0000000";
    col         <= "00";
    row         <= "000";
    num         <= "0000";
    W5          <= '0';
    X5          <= '0';
    Y5          <= '0';
    CURR_STATE  <= INIT;
    CURRENT_STATE <= SS6;
  elsif (CLK'event and CLK = '1') then
    R0_reg      <= R0_reg(2 downto 0) & R0;
    R1_reg      <= R1_reg(2 downto 0) & R1;
    R2_reg      <= R2_reg(2 downto 0) & R2;
    R3_reg      <= R3_reg(2 downto 0) & R3;
    R4_reg      <= R4_reg(2 downto 0) & R4;
    counter     <= n_counter;
    col         <= n_col;
    row         <= n_row;
    num         <= n_num;
    W5          <= n_W5;
    X5          <= n_X5;
    Y5          <= n_Y5;
    CURR_STATE  <= NX_STATE;
    CURRENT_STATE <= NEXT_STATE;
  end if;
end process;

process(CURR_STATE, K, R0_rise, R1_rise, R2_rise, R3_rise, R4_rise, col, counter, num,
        row, row_col)
begin

  -- defaults
  C0          <= '0';
  C1          <= '0';
  C2          <= '0';
  number_updated <= '0';
  n_counter   <= counter(5 downto 0) & '1'; -- increment counter
  n_col       <= col;
  n_row       <= row;
  n_num       <= num;

```

```

NX_STATE      <= CURR_STATE;
row_col       <= row & col;

case CURR_STATE is
when INIT =>
    C0          <= '1';
    C1          <= '1';
    C2          <= '1';
    n_counter   <= "0000000";
    NX_STATE    <= S0;

    if (R0_rise = '1') then
        n_row    <= "000";
    elsif (R1_rise = '1') then
        n_row    <= "001";
    elsif (R2_rise = '1') then
        n_row    <= "010";
    elsif (R3_rise = '1') then
        n_row    <= "011";
    elsif (R4_rise = '1') then
        n_row    <= "100";
    else
        NX_STATE <= INIT;
    end if;

when S0 =>
    C0          <= '1';
    if counter(6) = '1' then
        n_counter <= "0000000";
        if K = '1' then
            n_col  <= "00";
            NX_STATE <= DONE;
        else
            NX_STATE <= S1;
        end if;
    end if;

when S1 =>
    C1          <= '1';
    if counter(6) = '1' then
        n_counter <= "0000000";
        if K = '1' then
            n_col  <= "01";
            NX_STATE <= DONE;
        else
            NX_STATE <= S2;
        end if;
    end if;

when S2 =>
    C2          <= '1';
    if counter(6) = '1' then
        n_counter <= "0000000";
        n_col    <= "10";
        NX_STATE <= DONE;
    end if;

when DONE      =>
    C0          <= '1';
    C1          <= '1';

```

```

-- initial state waiting for input
-- Drive all columns

-- keep coutner in reset
-- default state is the next state

-- no action stay in INIT state

-- Check zero column
-- only drive the zero column
-- wait for inputs to settle out
-- reset counter
-- column is 0

-- Check first column
-- only drive the first column
-- wait for inputs to settle out
-- reset counter
-- column is 1

-- Check second column
-- only drive the second column
-- wait for inputs to settle out
-- reset counter
-- column is 2

-- input has been determined
-- Drive all columns

```

```

C2                                     <= '1';
case row_col is
  when "00000" => n_num <= "0001";  -- 1
  when "00001" => n_num <= "0010";  -- 2
  when "00010" => n_num <= "0011";  -- 3
  when "00100" => n_num <= "0100";  -- 4
  when "00101" => n_num <= "0101";  -- 5
  when "00110" => n_num <= "0110";  -- 6
  when "01000" => n_num <= "0111";  -- 7
  when "01001" => n_num <= "1000";  -- 8
  when "01010" => n_num <= "1001";  -- 9
  when "01100" => n_num <= "1010";  -- West
  when "01101" => n_num <= "1011";  -- 0
  when "01110" => n_num <= "1100";  -- East
  when "10000" => n_num <= "1101";  -- On
  when "10001" => n_num <= "1110";  -- Open
  when "10010" => n_num <= "1111";  -- Close
  when others => n_num <= "0000";  -- Invalid
end case;

if counter(6) = '1' then              -- wait for number to be updated
  number_updated <= '1';
  NX_STATE       <= INIT;              -- go back to INIT State
else
  NX_STATE       <= DONE;
end if;

when others =>
  null;
end case;
end process;

```

```
-----
-----
process (CURRENT_STATE, num, W5, X5, Y5, number_updated)
```

```
begin
```

```
  NEXT_STATE <= CURRENT_STATE;
```

```
  n_W5 <= W5;
```

```
  n_X5 <= X5;
```

```
  n_Y5 <= Y5;
```

```
  W    <= '0';
```

```
  X    <= '0';
```

```
  Y    <= '0';
```

```
  Z    <= '0';
```

```
case CURRENT_STATE is
```

```
  when SS0 =>
```

```
    if (number_updated = '1') then
```

```
      if Num = "0101" then
```

```
        NEXT_STATE <= SS1;
```

```
      elsif Num = "1101" then
```

```
        NEXT_STATE <= CURRENT_STATE;
```

```

    else
        NEXT_STATE <= SS6;
    end if;
end if;

when SS1 =>
    if (number_updated = '1') then
        if Num = "0101" then
            NEXT_STATE <= SS2;
        elsif Num = "1101" then
            NEXT_STATE <= SS0;
        else
            NEXT_STATE <= SS6;
        end if;
    end if;

when SS2 =>
    if (number_updated = '1') then
        if Num = "1100" then
            NEXT_STATE <= SS3;
        elsif Num = "1010" then
            NEXT_STATE <= SS4;
        elsif Num = "1101" then
            NEXT_STATE <= SS0;
        else
            NEXT_STATE <= SS6;
        end if;
    end if;

when SS3 => -- east
    if (number_updated = '1') then
        if Num = "1110" then -- open
            n_W5 <= '1';
            n_X5 <= '0';
            n_Y5 <= '1';
            NEXT_STATE <= SS5;
        elsif Num = "1111" then -- close
            n_W5 <= '1';
            n_X5 <= '0';
            n_Y5 <= '0';
            NEXT_STATE <= SS5;
        elsif Num = "1101" then -- on
            NEXT_STATE <= SS0;
        else
            NEXT_STATE <= SS6;
        end if;
    end if;

when SS4 => -- west
    if (number_updated = '1') then
        if Num = "1110" then -- open
            n_W5 <= '1';
            n_X5 <= '1';
            n_Y5 <= '0';
            NEXT_STATE <= SS5;
        elsif Num = "1111" then --close
            n_W5 <= '1';
            n_X5 <= '1';
            n_Y5 <= '1';
            NEXT_STATE <= SS5;
        end if;
    end if;

```

```

        elsif Num = "1101" then
            NEXT_STATE <= SS0;
        else
            NEXT_STATE <= SS6;
        end if;
    end if;
when SS5 =>
    W          <= W5;
    X          <= X5;
    Y          <= Y5;
    if (number_updated = '1') then
        if Num = "1101" then
            NEXT_STATE <= SS0;
        else
            NEXT_STATE <= SS6;
        end if;
    end if;
when SS6 =>
    if (number_updated = '1') then
        if Num = "1101" then
            NEXT_STATE <= SS0;
        else
            NEXT_STATE <= SS6;
        end if;
    end if;

    when others =>
        NEXT_STATE <= SS6;
    end case;
end process;

end transmitter_arch;

```

Appendix C VHDL Code

Section 2 Receiver Circuit

```
-- Title: Receiver/Motor&Light Control VHDL
-- Author: Alexa Maxwell Date: 1/20/2000 Last Revision: 4/15/2000
-- Description: This code processes the signal received from

library IEEE;
use IEEE.std_logic_1164.all;
entity receiver is
  port(
    I1, I2, I3, I4      : in std_logic; -- 4 inputs from receiver/decoder
    switch              : in std_logic; -- manual control switch on gate
    CLK, RST           : in std_logic; -- clock pulse and external reset
    Light              : out std_logic; -- output to control gate/warning lights
    Motor              : out std_logic; -- output to pulse motor
    CW                 : out std_logic; -- clockwise/counterclockwise motor motion
    OE_not             : out std_logic); -- signal to enable motor movement
end receiver;

architecture RTL of receiver is
  signal Count1 : integer; -- delay to control motor speed
  signal Count2 : integer; -- # of pulses to make motor revolve 83 times
  signal Xsig : std_logic_vector (3 downto 0); -- signal from receiver/decoder
  signal go : std_logic; -- signal for gate being in motion
  signal wait_for_switch : std_logic; -- wait until switch is released
  signal L : std_logic; -- light signal

begin

  OE_not <= not go;
  Xsig <= I1 & I2 & I3 & I4;
  Light <= L;

  process (RST, CLK, switch, I1, I2, I3, I4)
  begin

    if (RST = '1') then
      L <= '0';
      Motor <= '0';
      Count1 <= 0;
      Count2 <= 1921;
      go <= '0';
      wait_for_switch <= '0';

    elsif (CLK'event and CLK = '1') then

      if Count1 > 0 then
        Count1 <= Count1 - 1;
      elsif Count1 = 0 then
        Count1 <= 3000;
      end if;

    end if;

  end process;

end architecture RTL;
```

```

--Count down number of motor pulses
  if (go = '1') then
    if Count1 = 3000 then
      Count2 <= (Count2 - 1);
    end if;
    if Count2 = 0 then
      go <= '0';
    end if;
  end if;

--Motor Control Pulses
  if (Count1 > 1500) then
    Motor <= '1';
  elsif (Count1 < 1500 or Count1 = 1500) then
    Motor <= '0';
  end if;

--Close the gate with switch
  if (switch = '1' and L = '0' and wait_for_switch = '0' and go = '0') then
    CW <= '1';
    L <= '1';
    Count2 <= 1921;
    wait_for_switch <= '1';

--Open the gate with switch
  elsif (switch = '1' and L = '1' and wait_for_switch = '0' and go = '0') then
    CW <= '0';
    L <= '0';
    Count2 <= 1921;
    wait_for_switch <= '1';

--Wait until switch is released before starting
  elsif (switch = '0' and wait_for_switch = '1') then
    wait_for_switch <= '0';
    go <= '1';

--Close the gate with remote
  elsif (Xsig = "1110" and L = '0' and go = '0') then
    CW <= '1';
    L <= '1';
    Count2 <= 1921;
    go <= '1';

--Open the gate with remote
  elsif (Xsig = "1100" and L = '1' and go = '0') then
    CW <= '0';
    L <= '0';
    Count2 <= 1921;
    go <= '1';
  end if;

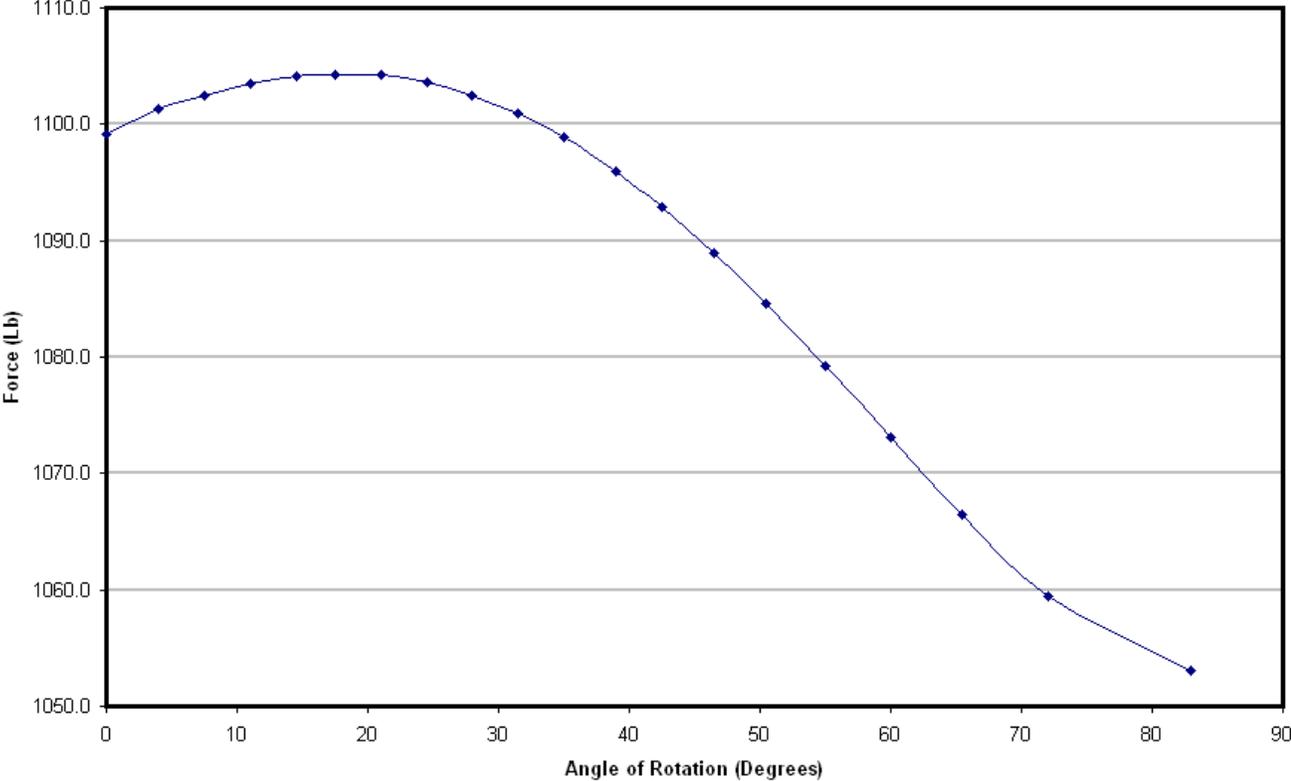
end if;
end process;

end RTL;

```

Appendix D Forces on the Actuator

Angle or Rotation Vs. Force



Appendix E Solid Works Drawing of Model

